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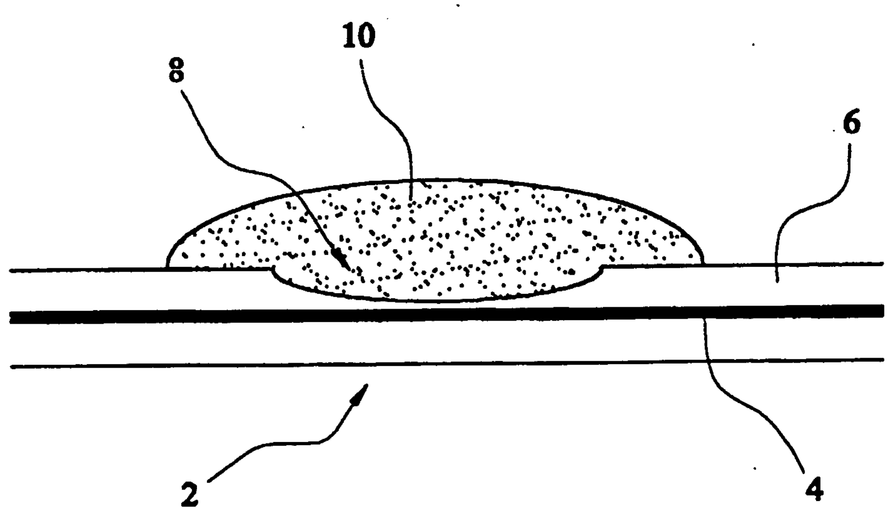

(57) Abstract

An optical fibre attenuator comprises an optical fibre (2) which comprises a central core (4) and an outer cladding (6). In a region (8) of the fibre, the outer cladding has been at least partially removed and/or the thickness of the outer cladding has been reduced. A material (10) has been provided at least partially over the cladding–removed region (8). The material (10) has a refractive index to couple light from the central core (4) of the optical fibre (2) so as to attenuate the light transmitted along the optical fibre (2).

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OPTICAL FIBRE ATTENUATOR AND METHOD OF ATTENUATING LIGHT TRANSMITTED THROUGH AN OPTICAL FIBRE

Technical Field

The present invention relates to an optical fibre attenuator and to a method of attenuating light transmitted through an optical fibre.

As used in this text, the term light covers other forms of electromagnetic radiation; however, infra-red and visible light in particular is contemplated.

Background

In a known single mode optical fibre, a propagating wave is contained within a central core section of the fibre through total internal reflection, the refractive index of the central core section being greater than the refractive index of the outer cladding. The guided wave has an associated evanescent field which extends some way into the cladding. The precise characteristics of the evanescent field are dependent upon the fibre parameters such as dimensions and refractive index, and the wavelength of the light propagated.

Statements of Invention

The present invention relates to an optical fibre attenuator comprising an optical fibre which comprises a central core and an outer cladding, in a region of the fibre the outer cladding having been at least partially removed and/or the thickness of the outer cladding having been reduced, a material having being provided at least partially over the region, the material having a refractive index to couple light from the central core of the optical fibre so as to attenuate the light transmitted along the optical fibre.

Preferably the outer cladding has been at least partially removed, for example by abrasion. Alternatively, preferably the thickness of the outer cladding is reduced, in particular by stretching the optical fibre.

The present invention also relates to a corresponding method of attenuating light transmitted through an optical fibre.

Preferably the material is selected dependent on its refractive index to provide a predetermined attenuation. Preferably for attenuation, the refractive index of the material is greater than that of the central core of the fibre.

Preferably the optical fibre is single mode optical fibre. Alternatively preferably the optical fibre is polarisation-maintaining fibre having two polarisation modes, the attenuations of transmitted light components in those two modes being selectable dependent upon the refractive index of the material.

Preferably the optical fibre attenuator is adjustable in its attenuation by adjusting the refractive index of the material.

Preferably the material is selected so as to have its refractive index dependent on temperature and the optical fibre attenuator includes a temperature control means to control the temperature of the material. Preferably the temperature control means is an electrically controllable heater. Preferably the material is an oil or polymer.

A plurality of the optical fibre attenuators can be

provided along an optical fibre, each being adjustable within predetermined ranges of attenuation settings.

Preferably an adjustable optical fibre attenuator can be controlled so as to have selectably high and low attenuation so as to act as a switch. Such switches can be used together with an optical fibre directional coupler to provide a switchable directional coupler. Preferably such switches are provided at the inputs or outputs of the switchable directional coupler.

Alternatively, a switchable directional coupler can comprise two or more optical fibre attenuators in each of which the thickness of the outer cladding is reduced in a region of the fibre by stretching the fibre, the fibres lying with their cladding-reduced regions in sufficient proximity to each other for electromagnetic coupling.

Detailed Description of the Preferred Embodiments

Preferred embodiments of the present invention will now be described by way of example and with reference to the Figures in which:

Figure 1 is a cross-section of a first optical fibre attenuator;

Figure 2 is an example graph of attenuation against refractive index of the overlay material for a first optical fibre attenuator;

Figure 2a is an example graph of attenuation against refractive index for an optical fibre attenuator where the optical fibre is polarisation-maintaining fibre.

Figure 3 is a cross-section of a second optical fibre

attenuator, the attenuation of which is controllable;

Figure 4 is a diagrammatic representation of an attenuation unit consisting of three controllable optical fibre attenuators;

Figure 5 is an example directional coupler using the controllable optical fibre attenuators; and

Figure 6 is an alternative switchable directional coupler.

As shown in Figure 1, the optical fibre attenuator consists of an optical fibre 2 having a central core 4 for light transmission and an outer cladding 6 which partially removed is a region 8. Partially removing the cladding 6 in a region 8 of the fibre 2 enables access to the evanescent field when light is transmitted.

The cladding 6 is removed using a grinding/polishing technique and the amount of cladding 6 removed, i.e. the level of interaction with the evanescent field, defines the level of attenuation achievable from a specific device. By monitoring the level of light transmitted through the fibre 2 during the grinding and polishing operations, the amount of cladding 6 removed is controlled.

In some alternative embodiments the fibre cladding is removed by other methods besides or in addition to abrading, e.g. chemical etching.

A layer of another material 10 is laid over the region 8 of optical fibre 2 from which the cladding has been at least partially removed.

The level of power transmitted by an optical fibre 2 with the cladding 6 partially removed, is dependent upon

the refractive index of the material 10 replacing the removed cladding. Figure 2 shows a typical variation of transmitted power as a function of the refractive index of the material 10 replacing the cladding. When the refractive index of the material is below that of the core 4 the light is guided along the fibre 2. However, when the refractive index of the material 10 is greater than that of the core 4, light is coupled out of the guide into radiation modes, i.e. as an evanescent field, resulting in attenuation of the level of light transmitted along the core 4.

In embodiments where the optical fibre 2 is polarisation maintaining fibre rather than single mode optical fibre, the polarisation maintaining fibre can be aligned and is ground either along a selected axis or at an angle to the axis. The two polarisation modes of the polarisation maintaining fibre have different effective refractive indices in the abraded region, therefore the attenuation for each of the modes for a specific refractive index of the overlay material 10 is different. A typical variation of throughput light as a function of refractive index of the material 10 replacing the cladding is shown in Figure 2a. The optical fibre attenuator operates in one or more of the three ways dependent on the properties of the material 10 overlying the abraded region of the fibre. The first way is where the refractive index of the material is adjusted such that both polarisation modes can pass through the fibre with virtually no loss. The second way is when one polarisation mode has a lower attenuation than the other, providing an effective polarising action. The third way is where both modes experience a high attenuation. In some embodiments, the refractive index of the overlay material is variable.

Rather than at least partially removing the cladding

by e.g. grinding, an alternative method to access the evanescent field, which is used in some alternative embodiments, is to taper the fibre. This is achieved by heating a section of fibre to be tapered such that the silica softens and then pulling the fibre to taper the cross section. This has the effect of reducing both the cladding and core diameters and the evanescent field extends beyond the cladding locally in the tapered region.

Fixed Attenuators

One option is to use a material 10 such as a polymer which is environmentally stable and has a refractive index greater than that of the core so as to provide a fixed attenuation. In this case, the fibre 2 is ground and polished whilst monitored using an oil for lubrication having the value of refractive index of the material or some other known refractive index. The polishing process is stopped once the required attenuation is reached. Applying the material 10 to the region 8 and fixing the material 10 firmly to the fibre 2 provides a stable fixed attenuator. Attenuators of various selected attenuations are producible in this way.

Variable Attenuators

As shown in Figure 2, there are transitional states in which the level of power remaining in the fibre 2 can be controlled by varying the refractive index of the material 10. Two regions can be identified, the first (A) is the steep slope where the refractive index of the material 10 is close to that of the core 4 and the other (B) is a shallower slope appearing at index range above that of the core 4. Either of these two regions (A) and (B) are usable to control the power of light transmitted by the optical fibre 2.

The refractive index of the material 10 in contact with the core 4 can be controlled by way of external effects such as forces, thermal changes, electro-optic changes, magneto-optic changes or optically induced changes.

A thermally controlled attenuator 11 is described below.

As shown in Figure 3, the fibre 2' with its region 8' of cladding 6' partially removed is placed within a sealed capillary tube 12 filled with material 10' and attached to a miniature temperature controlled heater 14 or Peltier element. Other types of heaters could be used. The whole device is insulated from the outside environment. An electronic control unit 6 is used to control the heater 14 to vary the temperature of the material 10' to provide continuous electronic adjustment of the attenuation.

The material 10' is selected to have a large refractive index variation with the control signal, in this case temperature. Oils and polymers having suitable properties are available as the material 10'. An example of an oil which can be used is paraffin. An example of polymers which can be used are polymethylmethacrylate (p.m.m.a.) or polyimide.

If oil is to be used, the fibre 2 is ground and polished and mounted in a small capillary tube 12 of metal or silica which is filled with the oil. The oil is selected to give the required refractive index variation over the required operational temperature range. In general the control temperature range is higher than the anticipated environmental temperature range. The ends of the tube 12 are sealed such that the fibre 2 and oil are

completed encapsulated.

In other examples, where polymer is used, the material 10' of polymer is attached directly to the optical fibre 2' using one of a number of known polymer layer processing methods such as dipping. Providing a good contact is made with the optical fibre 2, the material 10' of polymer acts as a replacement cladding.

The electronic control unit 16 is designed such that the temperature of the heater 14 is dependent upon the resistance selected at the input to the heater 14. In this way a series of resistors can be switched to provide several different temperature, hence attenuation, settings. Different attenuation steps can be achieved by an appropriate selection of resistors.

Connecting several variable attenuators, as described above, in series with each attenuator having different attenuation settings available, allows a precise attenuation from within a wide range of to be selected. An example is shown in Figure 4. This attenuation unit 18 consists of three variable attenuators 1. First attenuator 20 has attenuation steps ten times greater than the second attenuator 22 and the second attenuator 22 ten times greater than the third attenuator 24.

<u>Two Level Operation</u>

Two modes of operation are selectable for a variable attenuator 11 by switching between two temperatures of the material 10'. One mode allows at least substantially all of the signal to pass along the fibre 2'. The other mode allows light passage along the fibre 2' to be stopped. This is essentially an on/off switching.

Switchable Directional Coupler

Figure 5 shows switchable directional coupler 26 in which two attenuators 11, 11 used in two mode operation as described above, are attached to two ports c, d of a directional coupler 28. Input to port (a) will produce half the power at port c and half at port d. Therefore four output options are available by switching the two attenuators 11. The switchable directional coupler 26 can be used in the opposite direction to select input signal levels to the directional coupler 28. A network can be provided by using further directional couplers 28 each having further attenuators 11 for each of their output and/or input paths. The condition of each of the attenuators 11, such as in two level operations, is controlled electronically.

An alternative switchable directional coupler 30 is shown in Figure 6. Such a switchable directional coupler 30 is fabricated by fusing two fibres together and pulling them to taper the joined section until the required level of light is achieved at the two output fibres A′, B′. Such a process is used to draw the fibres such that in the fused region 32 the evanescent fields of the two fibre cores extend beyond the cladding. The level of power coupled to the output ports A′, B′ is then a function of the refractive index of the medium 10″ surrounding the fused region 32. Modifying this refractive index allows control of the power output from each port A′, B′. By control of the refractive index as described previously in relation to variable attenuators, the power can be directed from one port to a selected other. This allows switching of the power. Many such devices can be joined together i.e. cascaded to provide multiple switching.

As shown in Figure 6, transmission of power input

either to port 1 or port 2 is controlled to ports A′ and B′ by varying the refractive index of the surrounding material 10″ through heating. The sum of the power outputs from A′ & B′ equals the power input to the switchable directional coupler minus the intrinsic loss of the switchable directional coupler.

In an alternative switchable directional coupler (not shown) two or more fibres are located with their regions of reduced outer cladding in sufficient proxiity to enable electromagnetic coupling through the material between the fibres.

CLAIMS:

1. An optical fibre attenuator comprising an optical fibre (2) which comprises a central core (4) and an outer cladding (6), in a region (8) of the fibre the outer cladding having been at least partially removed and/or the thickness of the outer cladding having been reduced, a material (10) having being provided at least partially over the region, the material having a refractive index to couple light from the central core (4) of the optical fibre so as to attenuate the light transmitted along the optical fibre.

2. An optical fibre attenuator according to claim 1, in which the material (10) is selected dependent on its refractive index to provide a predetermined attenuation.

3. An optical fibre attenuator according to claim 1 or claim 2, in which for attenuation, the refractive index of the material (10) is greater than that of the central core of the fibre.

4. An optical fibre attenuator according to any preceding claim, in which the optical fibre (2) is single mode optical fibre.

5. An optical fibre attenuator according to any of claims 1 to 3, in which the optical fibre (2) is polarisation maintaining fibre having two polarisation modes, the attenuations of transmitted light components in those two modes being selectable dependent upon the refractive index of the material (10).

6. An optical fibre attenuator according to any preceding claim, in which the optical fibre attenuator is adjustable

in its attenuation by adjusting the refractive index of the material (10).

7. An optical fibre attenuator according to claim 6, controllable so as to have selectably high and low attenuation so as to act as a switch.

8. An optical fibre attenuator according to any preceding claim, in which the material (10, 10′) is selected so as to have its refractive index dependent on temperature and the optical fibre attenuator includes a temperature control means (14, 16) to control the temperature of the material.

9. An optical fibre attenuator according to claim 8, in which the temperature control means is an electrically controllable heater (14).

10. An optical fibre attenuator according to any preceding claim, in which the material (10. 10′) is an oil or polymer.

11. An optical fibre attenuator according to any of claims 1 to 10, in which the outer cladding (6, 6′) has been at least partially removed.

12. An optical fibre attenuator according to any of claims 1 to 10, in which the thickness of the outer cladding is reduced by stretching the optical fibre.

13. An attenuator comprising a plurality of the optical fibre attenuators according to any preceding claim provided along an optical fibre, each being adjustable within predetermined ranges of attenuation settings.

14. A switchable directional coupler (26) comprising a

plurality of optical fibre attenuators (11), each according to claim 7, and an optical fibre directional coupler (28).

15. A switchable directional coupler according to claim 14 in which the optical fibre attenuators (11) are provided at the inputs and outputs (c, d) of the switchable directional coupler (28).

16. A switchable directional coupler (Fig. 6) comprising at least two optical fibre attenuators according to any of claims 1 to 12 with their cladding reduced regions lying in sufficient proximity to each other for electromagnetic coupling.

17. A method of attenuating light transmitted through an optical fibre (2), the optical fibre comprising a central core (4) and an outer cladding (6), by at least partially removing and/or reducing the thickness of the outer cladding in a region (8) of the fibre, and providing a material (10) at least partially over the cladding-reduced region, the material having a refractive index selected to couple light from the central core of the optical fibre so as to attenuate the light transmitted along the optical fibre (2).

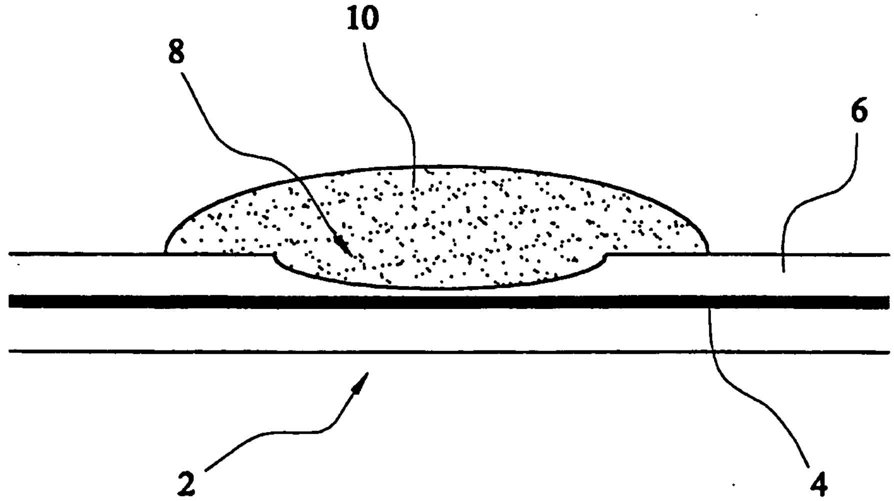
10
8
6
2
4

FIG. 1

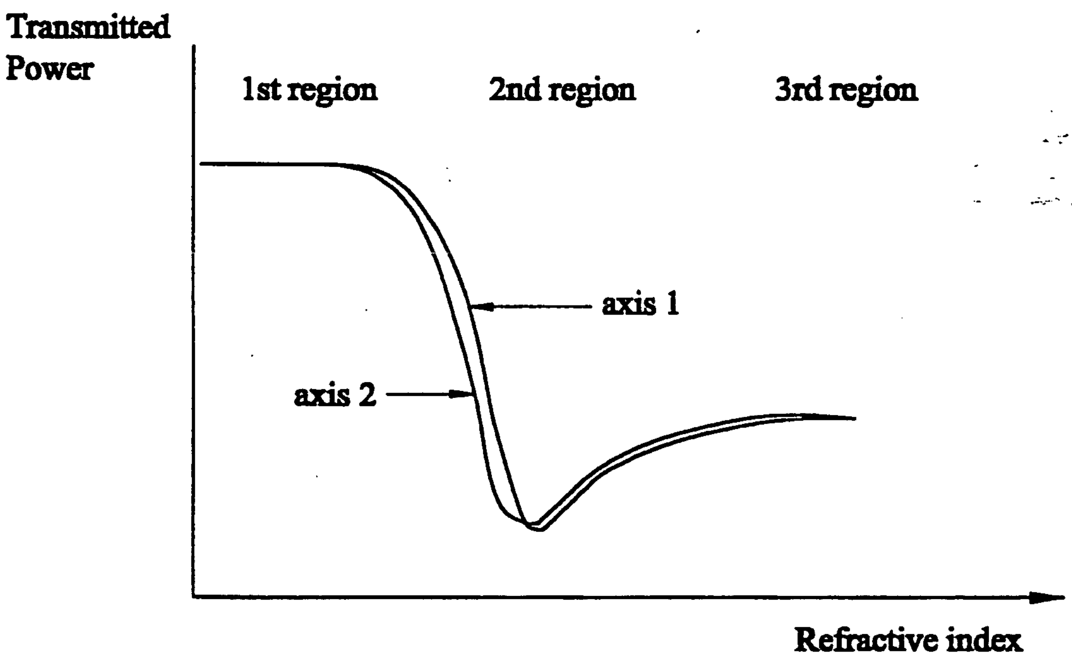
Transmitted Power
1st region
2nd region
3rd region
axis 1
axis 2
Refractive index

FIG. 2a

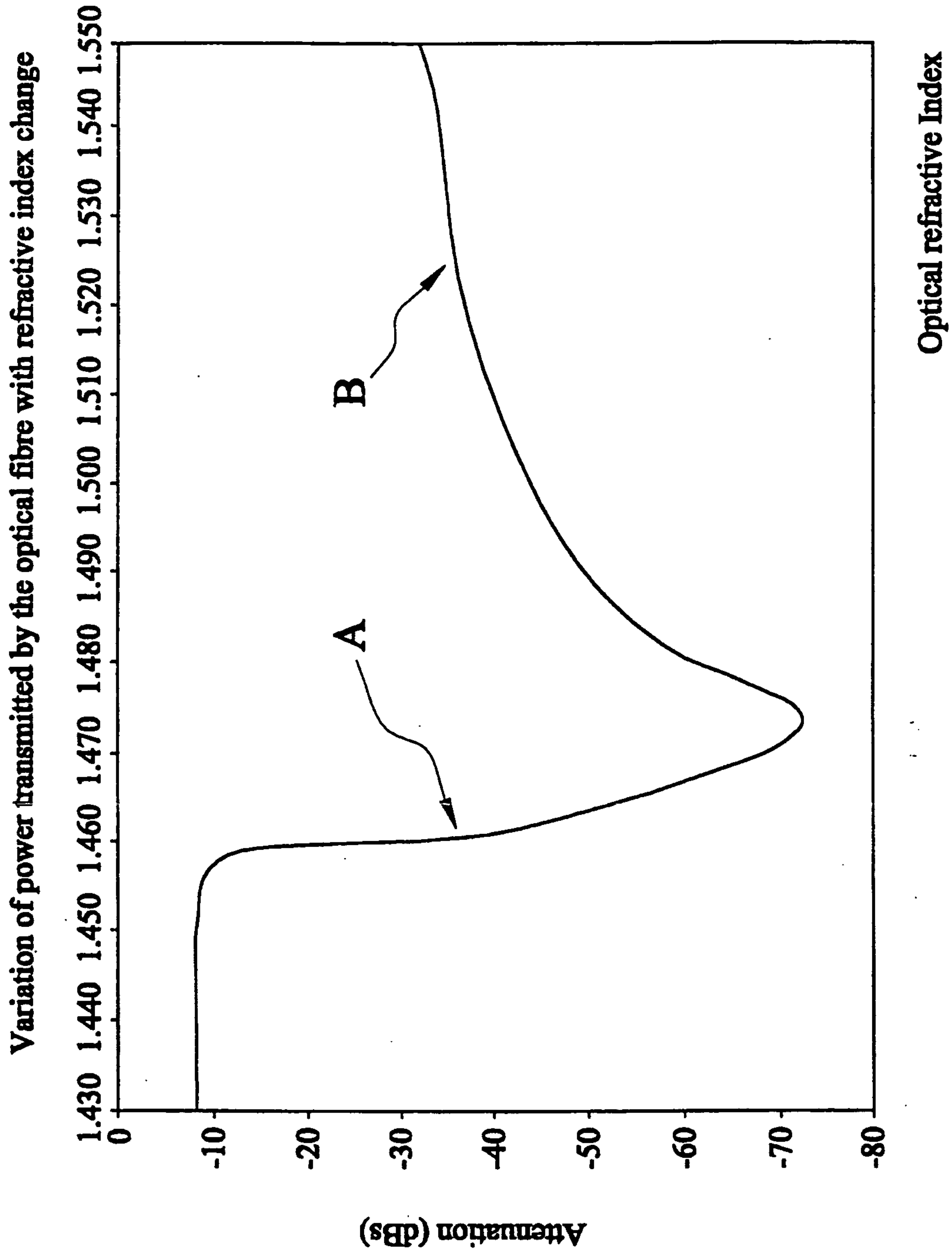
Variation of power transmitted by the optical fibre with refractive index change
1.430 1.440 1.450 1.460 1.470 1.480 1.490 1.500 1.510 1.520 1.530 1.540 1.550
0 -10 -20 -30 -40 -50 -60 -70 -80
Attenuation (dBs)
Optical refractive Index
A
B

FIG. 2

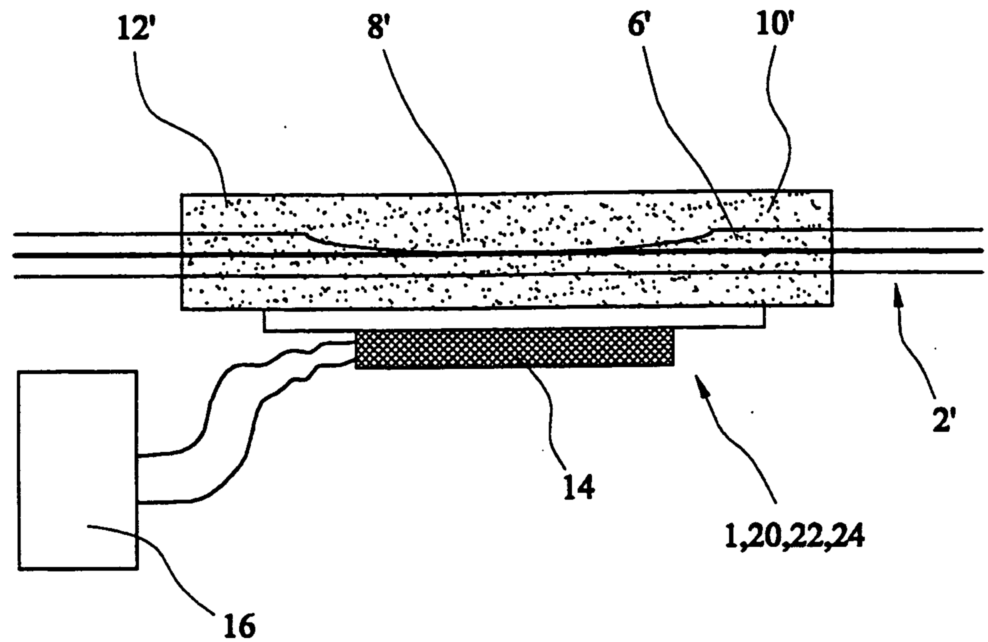
12'
8'
6'
10'
2'
14
1,20,22,24
16

FIG. 3

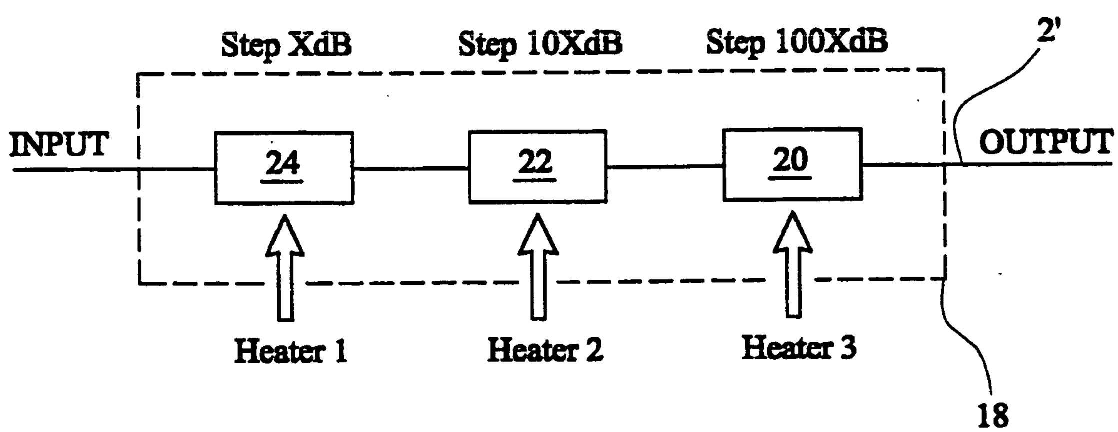
Step XdB
Step 10XdB
Step 100XdB
2'
INPUT
24
22
20
OUTPUT
Heater 1
Heater 2
Heater 3
18

FIG. 4

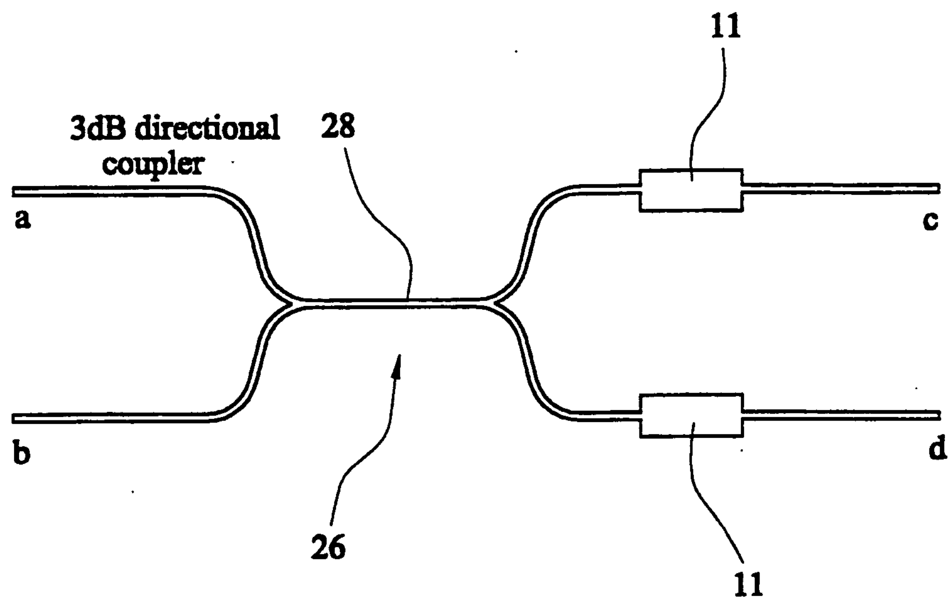
11
3dB directional
coupler
28
a
c
b
d
26
11

FIG. 5

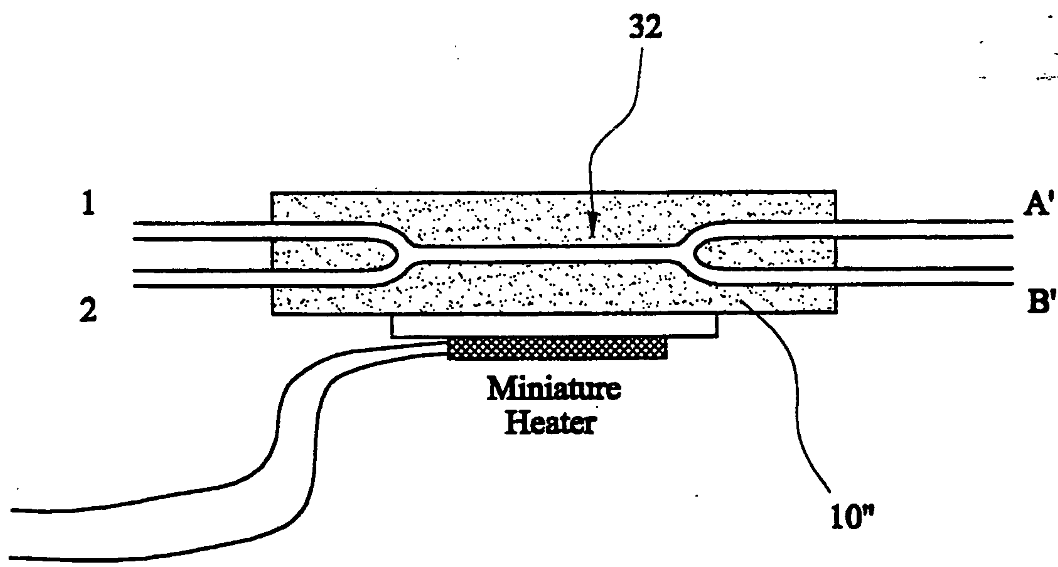
32
1
A'
2
B'
Miniature
Heater
10"

FIG. 6

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 00/00574

A. CLASSIFICATION OF SUBJECT MATTER

G02B6/10,G02B6/26,G02B6/28,G02F1/01

According to International Patent Classification (IPC) or to both national classification and IPC 7

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G02B,G02F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 95/05617 A (TELEFONAKTIEBOLAGET LM ERICSSON) 23 February 1995, page 3, lines 22-31, page 9, line 3 - page 11, line 18, page 12, line 30 - page 13, line 37.	1-4, 6,11, 16,17
Y		14,15
	--	
Y	DE 4343943 A (SIEMENS) 29 June 1995, fig. 1,2, claims 1,2,4,5.	14,15
A		1
	--	
X	US 4778237 A (SORIN et al.) 18 October 1988, column 2, line 43 - column 6,	1-4,6, 8,10, 11,17

[X] Further documents are listed in the continuation of box C.

[ ] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
03 May 2000	04.07.00

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	line 63, column 7, line 35 - column 8, line 10.	
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A		13-15

ANHANG	ANNEX	ANNEXE
Zum internationalen Recherchenbericht über die internationale Patentanmeldung Nr.	To the International Search Report to the International Patent Application No.	Au rapport de recherche International relativ à la demande de brevet international n°

PCT/GB 00/00574 SAE 268636

In diesem Anhang sind die Mitglieder der Patentfamilien der im obengenannten internationalen Recherchenbericht angeführten Patentdokumente angegeben. Diese Angaben dienen nur zur Unterrichtung und erfolgen ohne Gewähr.

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		EP A1 664894	02-08-1995
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